EXHIBIT 602.10

The **sinoatrial (sinuatrial) node,** also known as the SA **node,** or **pacemaker,** is a compact mass of cells located in the right atrial wall inferior to the opening of the superior vena cava (Figure 20-7a). The SA node initiates each cardiac cycle and thereby sets the basic pace for the heart rate. The SA node spontaneously depolarizes and generates action potentials faster than other components of the conduction system and myocardium. As a result, nerve impulses from the SA node spread to other areas of the conduction system and myocardium, and stimulate them so frequently that they are not able to generate action potentials at their own inherent rates. Thus, the faster rate of discharge of the SA node sets the rhythm for the rest of the heart, hence its common name pacemaker. The rate set by the SA node may be altered by nerve impulses from the autonomic nervous system or by certain blood-borne chemicals such as thyroid hormones and epinephrine.

Once an action potential is initiated by the SA node, the impulse spreads out over both atria, causing them to contract, and at the same time depolarizing the **atrioventricular (AV) node.** Because of its location near the inferior portion of the interatrial septum, the AV node is one of the last portions of the atria to be depolarized.

From the AV node, a tract of conducting fibers called the **atrioventricular (AV) bundle (bundle of His)** runs through the cardiac skeleton to the top of the interventicular septum. It then continues down both sides of the septum as the **right** and **left bundle branches.** The atrioventricular bundle distributes the action potential over the medial surfaces of the ventricles. Actual contraction of the ventricles is stimulated by **conduction myofibers (Purkinje fibers)** that emerge from the bundle branches and pass into the cells of the myocardium.

ELECTROCARDIOGRAM

Impulse transmission through the conduction system generates electrical currents that can be detected on the body's surface. A recording of the electrical changes that accompany the cardiac cycle is called an **electrocardiogram (ECG or EKG).** The instrument used to record the changes is an *electrocardiograph.*

Each portion of the cardiac cycle produces a different electrical impulse. These impulses are transmitted from the electrodes to a recording pen that graphs the impulses as a series of up-and-down waves called *deflection waves.* In a typical record (Figure 20-7b), three clearly recognizable waves accompany each cardiac cycle. The first, called the **P wave,** is a small upward wave. It indicates atrial depolarization—the spread of an impulse from the SA node through the muscle of the two atria. A fraction of a second after the P wave begins, the atria contract. The second wave, called the **QRS wave (complex),** begins as a downward deflection, continues as a large, upright, triangular wave, and ends as a downward wave at its base. This deflection represents ventricular depolarization, that is, the spread of the electrical impulse through the ventricles. The third recognizable deflection is a dome-shaped **T wave.** This wave indicates ventricular repolarization. There is no deflection to show atrial repolarization because the stronger QRS wave masks this event.

In reading an electrocardiogram, it is important to note the size of the deflection waves at certain time intervals. Enlargement of the P wave, for example, indicates enlargement of the atrium, as in mitral stenosis. In this condition, the mitral valve narrows, blood backs up into the atrium, and there is expansion of the atrial wall.

The *P-R interval* is measured from the beginning of the P wave to the beginning of the R wave. It represents the conduction time from the beginning of atrial excitation to the beginning of ventricular excitation. The P-R interval is the time required for an impulse to travel through the atria and atrioventricular node to the remaining conducting tissues. The lengthening of this interval, as in atherosclerotic heart disease and rheumatic fever, occurs because the heart tissue covered by the P-R interval, namely the atria and atrioventricular node, is scarred or inflamed. Thus the impulse must travel at a slower rate and the interval is lengthened. The normal P-R interval covers no more than 0.2 sec.

An enlarged Q wave may indicate a myocardial infarction (heart attack). An enlarged R wave generally indicates enlarged ventricles.

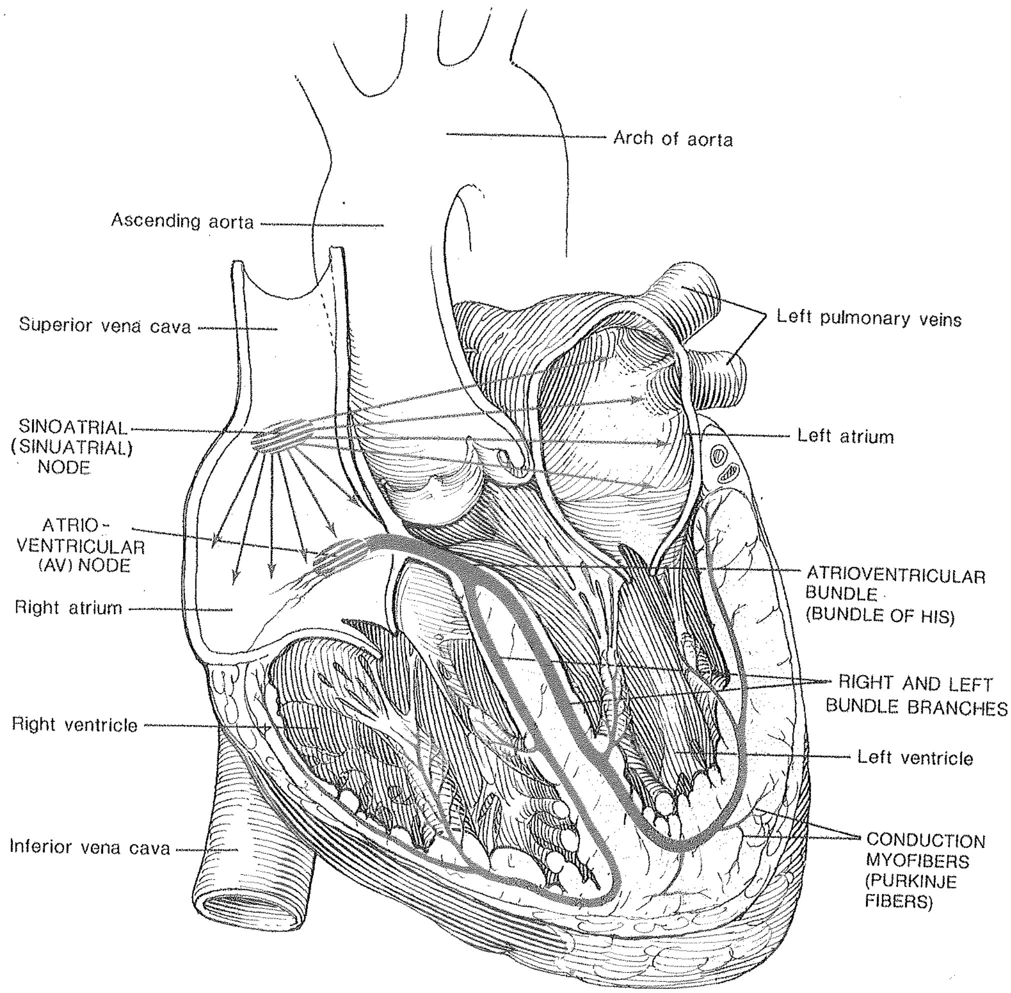
The *S-T segment* begins at the end of the S wave and terminates at the beginning of the T wave. It represents the time between the end of the spread of the impulse through the ventricles and repolarization of the ventricles. The S-T segment is elevated in acute myocardial infarction and depressed when the heart muscle receives insufficient oxygen.

The T wave represents ventricular repolarization. It is flat when the heart muscle is receiving insufficient oxygen, as in atherosclerotic heart diesease. It may be elevated when the body's potassium level is increased.

The ECG is useful in diagnosing abnormal cardiac rhythms and conduction patterns and following the course of recovery from a heart attack. It can also detect the presence of fetal life or determine the presence of several fetuses. For some people, ECG monitoring may be done by using a *Holter monitor.* This is an ambulatory system in which the monitoring hardware is worn by an individual while going about everyday routines. The Holter monitor is used especially to detect rhythm disorders in the conduction system. It is also used to correlate rhythm disorders and symptoms and to follow the effectiveness of drugs.

CLINICAL APPLICATION

When major elements of the conduction system are disrupted, an irregular heart rhythm may occur. In one type of rhythm disturbance, the ventricles fail to receive atrial impulses, causing the ventricles and atria to beat independently of each other. In patients with such a condition, normal heart rhythm can be restored and maintained with an **artificial pacemaker,** a device that sends out small electrical charges that stimulate the heart. It consists of three basic parts: a *pulse generator,* which contains the battery cells and produces the impulse; a *lead,* which is a flexible wire connected to the pulse generator that delivers the impulse to the



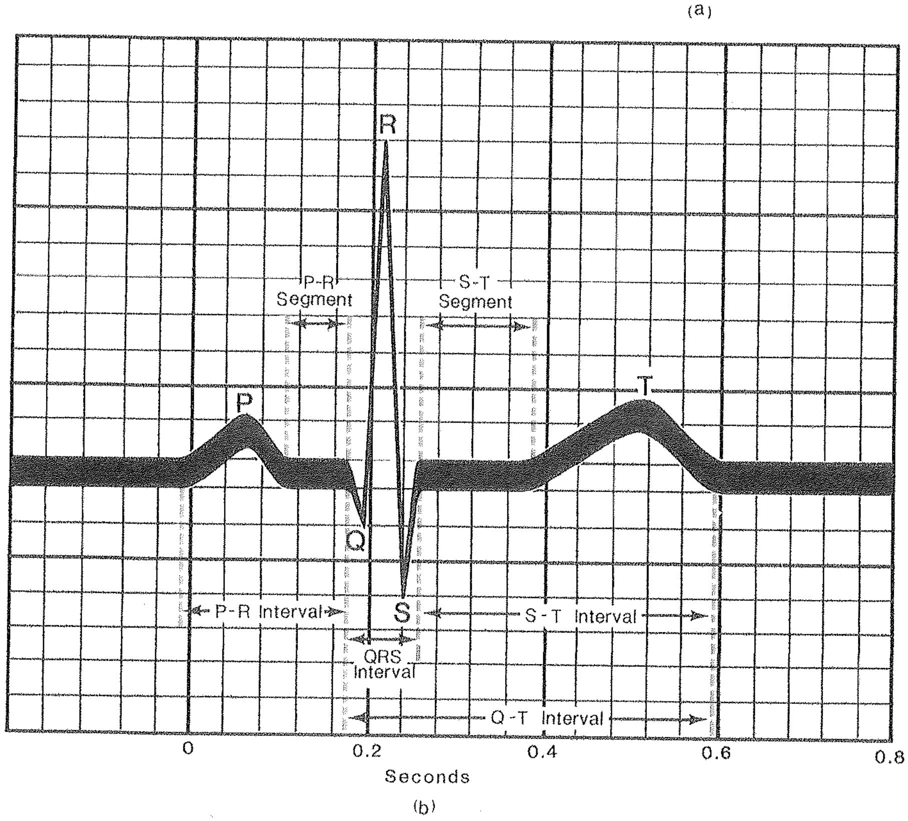


FIGURE 20-7 Conduction system of the heart. (a) Location of the nodes and bundles of the conduction system. (b) Normal electrocardiogram of a single heartbeat, enlarged for emphasis.

electrode; and an *electrode,* which makes contact with a portion of the heart and delivers the charge to the heart.

BLOOD FLOW THROUGH THE HEART

Two phenomena control the movement of blood through the heart: the opening and closing of the valves and the contraction and relaxation of the myocardium. Both these activities occur without direct stimulation from the nervous system. The valves are controlled by pressure changes in each heart chamber. The contraction of the cardiac muscle is stimulated by its conduction system.

Blood flows from an area of higher pressure to an area of lower pressure. The pressure developed in a heart chamber is related primarily to the chamber's size. For example, if the chamber size decreases, the pressure increases. The pressure in the atria is called **atrial pressure,** that in the ventricles is called **ventricular pressure,** and pressure in the aorta and pulmonary trunk is referred to as **arterial pressure.** The relationship of these pressures to a heartbeat in the left side of the heart is shown in Figure 20-8b. Although the pressures in the right side of the heart are somewhat lower, the same pattern exists.

CARDIAC CYCLE

In a normal heartbeat, the two atria contract while the two ventricles relax. Then, when the two ventricles contract, the two atria relax. The term **systole** (SIS-tō-lē) refers to the phase of contraction; **diastole** (dī-AS-tō-lē) is the phase of relaxation. A **cardiac cycle,** or complete heartbeat, consists of a systole and diastole of both atria plus the systole and diastole of both ventricles.

For purposes of our discussion, we will divide the cardiac cycle into the following phases: As you read the description, refer to Figure 20-8.

1. **Atrial Systole (Contraction)** Under normal conditions, blood flows continuously from the superior vena cava, inferior vena cava, and coronary sinus into the right atrium and from the pulmonary veins into the left atrium. The bulk of blood, about 70 percent, flows passively from the atria into the ventricles, even before atrial contraction occurs. When the SA node fires, the atria depolarize. This is followed by atrial contraction. Atrial depolarization produces the P wave on the ECG. Contraction of the atria forces its remaining blood into the ventricles. This final push accounts for only about 30 percent of the blood passed into the ventricles. Thus, atrial contraction is not really necessary for ventricular filling at normal heart rates. During atrial systole, deoxygenated blood passes through the open tricuspid valve from the right atrium into the right ventricle, and oxygenated blood passes through the open bicuspid valve from the left atrium to the left ventricle.

If you look at the atrial pressure curve in Figure 20-8b, you will notice that there are several pressure elevations, the a, c, and v waves. The *a wave* is produced by atrial contraction. The *c wave* is caused by ventricular contraction, which makes the atrioventricular values bulge into the atria. The *v wave* is due to atrial filling while the atrioventricular valves are closed during ventricular contraction.

2. **Ventricular Filling.** When the ventricles are contracting, the atrioventricular valves are closed and atrial pressure increases as blood fills the atria. During atrial diastole (relaxation), deoxygenated blood from various parts of the body enters the right atrium and oxygenated blood from the lungs enters the left atrium. But, once ventricular contraction is over, ventricular pressure falls. The higher atrial pressure pushes the atrioventricular valves open and blood fills the ventricles.

The major part of **ventricular filling** occurs immediately upon opening of the atrioventricular valves. The first third of ventricular filling is the *period of rapid filling.* During the middle third, called *diastasis,* only a small amount of blood flows into the ventricles. This is blood that continuously empties into the right atrium from the superior vena cava, inferior vena cava, and coronary sinus, and into the left atrium from the pulmonary veins, and passes through the atria directly into the ventricles. During the last third of ventricular filling, the atria contract. As noted earlier, this accounts for about 30 percent of the blood that fills the ventricles.

3. **Ventricular Systole (Contraction).** Near the end of atrial systole, the action potential from the SA node passes to the AV node and through the ventricles, causing them to depolarize and contract. This is represented as the QRS complex in the ECG. The beginning of ventricular contraction coincides with the first heart sound. At the onset of ventricular contraction, there is an abrupt rise in ventricular pressure that causes the atrioventricular valves to close. The first 0.05 seconds of ventricular systole is known as **isovolumetric contraction** because ventricular volume is constant (Figure 20-8c). It is the interval of time between the start of ventricular systole and the opening of the semilunar valves. During this time, there is contraction of the ventricles but no emptying; there is a rapid rise in ventricular pressure.

Once ventricular pressure exceeds arterial pressure, the semilunar valves open and blood is forced from the ventricles into their respective arteries. This is called the **ejection period** and lasts for about 0.25 seconds, until the semilunar valves close. The blood pumped by each ventricle during ejection is about half the content of the ventricle and is known as stroke volume (discussed shortly).

4. **Ventricular Diastole (Relaxation).** At the end of ventricular contraction, the ventricles suddenly begin their relaxation. The period of time, about 0.05 seconds between the opening of the atrioventricular valves and the closing of the semilunar valves is termed **isovolumetric relaxation.** It is characterized by a drastic decrease in ventricular pressure without a change in ventricular volume (Figure 20-8c). The higher arterial pressure causes blood to flow back toward the ventricles. This results in closure of the semilunar valves. Closure of the aortic semilunar valve produces a brief rise in arterial (aortic) pressure (dicrotic notch), shown in Figure 20-8b, and the second heart sound.

Firing of the SA node results in atrial depolarization, followed by atrial contraction, and the beginning of another cardiac cycle.

TIMING

If we assume that the average heart beats 75 times per minute, then each cardiac cycle requires about 0.8 sec. During the first 0.1 sec, the atria contract and the ventricles relax. The atrioventricular valves are open, and the semilunar valves are closed. For the next 0.3 sec, the atria are relaxing and the ventricles are contracting. During the first part of this period, all valves are closed; during the second part, the semilunar valves are open.

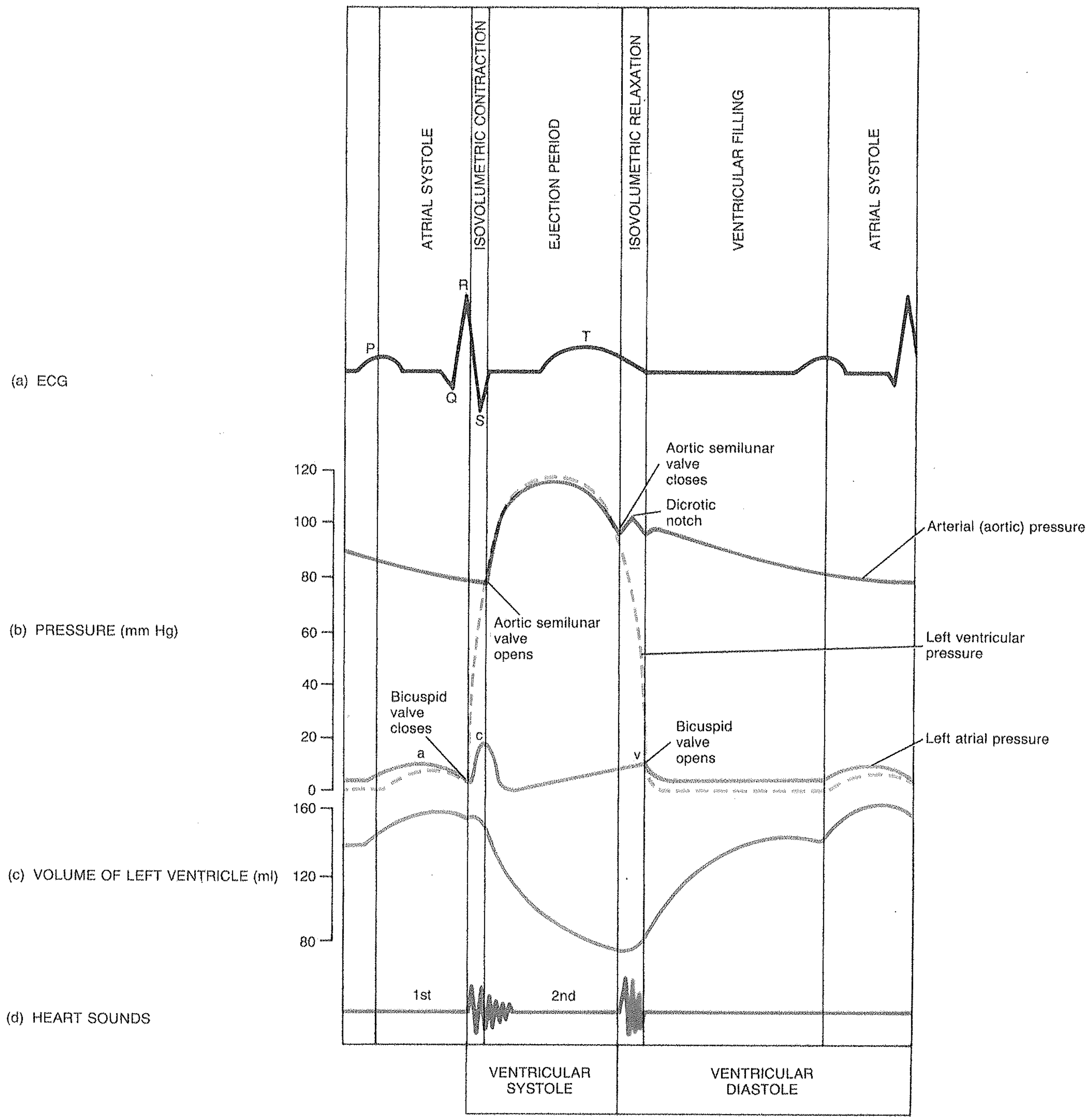


FIGURE 20-8 Cardiac cycle. (a) ECG related to the cardiac cycle. (b) Left atrial, left ventricular, and arterial (aortic) pressure changes along with the opening and closing of valves during the cardiac cycle. The letters a, c, and v represent the elevation waves of the left atrial pressure curve. (c) Left ventricular volume during the cardiac cycle. (d) Heart sounds related to the cardiac cycle.

The last 0.4 sec of the cycle is the *relaxation* (*quiescent*) *period* and all chambers are in diastole. In a complete cycle, then, the atria are in systole 0.1 sec and in diastole 0.7 sec; the ventricles are in systole 0.3 sec and in diastole 0.5 sec. For the first part of the relaxation period, all valves are closed; during the latter part, the atrioventricular valves open and blood starts draining into the ventricles. When the heart beats faster than normal, the relaxation period is shortened accordingly.

SOUNDS

The act of listening to sounds within the body is called **auscultation** (*auscultare* = to listen; aws-kul-TĀ-shun)

Gerard J. Tortora
Nicholas P. Anagnostakos

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